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PATENT APPLICATION

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**APPLICATION FOR
UNITED STATES LETTERS PATENT**

TO ALL WHOM IT MAY CONCERN:

Be it known that WE, Hany Aziz, Nan-Xing Hu, Zoran D. Popovic, and James M. Duff, have invented

OLEDs HAVING LIGHT ABSORBING ELECTRODE

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OLEDs HAVING LIGHT ABSORBING ELECTRODE

BACKGROUND OF THE INVENTION

Organic light emitting devices (OLEDs) represent a promising technology for display applications. A typical organic light emitting device includes a transparent first electrode, which usually acts as a hole-injecting anode; a luminescent region comprising one or more electroluminescent organic layer(s); and a second electrode (also called a "back electrode"), which usually acts as an electron-injecting cathode. In order to facilitate electron injection from the back electrode into the electroluminescent layer(s), the back electrode generally is formed of a low work function metal, and therefore is highly reflective. When a voltage is applied across the first and second electrodes, light is emitted from the electroluminescent layer(s) and through the transparent anode. When viewed under high ambient illumination, the reflective back electrode reflects a substantial amount of the ambient illumination to the observer, which results in higher ratios of reflected illumination as compared to the device's own emission, which results in "washout" of the displayed image.

In order to improve the contrast of electroluminescent displays in general, light absorbing layers as described, for example, in U.S. Patent 4,287,449, or optical interference members as described, for example, in U.S. Patent 5,049,780, have been used to reduce the ambient illumination reflection. Both of these approaches involve the use of optical films made of materials that are generally non-conductive. These properties limit the applicability of such materials to organic light emitting devices, which, unlike inorganic electroluminescent phosphor devices, require the direct injection of charges from the electrodes to the electroluminescent layer(s). In addition, the fabrication of such optical films, essentially from dielectric inorganic materials, often requires the use of sputtering or electron beam evaporation techniques. These fabrication techniques require additional instrumentation to be incorporated into the otherwise relatively simple fabrication process of organic light emitting devices by thermal evaporation or spin coating techniques. Also, in cases using optical interference effects for achieving improved contrast, such as disclosed, for example, in U.S. Patent 5,049,780, it is usually required to use more than one optical film in order to achieve the desired improvement, which is disadvantageous to the fabrication

process. Furthermore, the resulting improvement in display contrast is inevitably dependent on the viewing angle.

Thus, there is a need, addressed by the present invention, for new OLEDs that avoid or minimize a number of the disadvantages described above for conventional electroluminescent devices.

Organic light emitting devices are disclosed in the following:

Pending US Serial No. 09/800,716 (titled "cathodes for electroluminescent devices having improved contrast and reduced dark spot growth"), assigned to Xerox Corporation; and

O. Renault et al., "A low reflectivity multilayer cathode for organic light-emitting diodes," *Thin Solid Films*, Vol. 379, pp. 195-198 (December 8, 2000);

International Application Publication No. WO 01/08240 A1; and

David Johnson et al., "Contrast Enhancement of OLED Displays," http://www.luxell.com/pdfs/OLED_tech_ppr.pdf, pp. 1-3 (April 2001).

SUMMARY OF THE INVENTION

The present invention is accomplished in embodiments by providing an organic light emitting device comprising:

a first electrode;

a second electrode; and

a luminescent region including an organic electroluminescent material between the first electrode and the second electrode, wherein one of the first electrode and the second electrode includes both a substantially transparent charge injecting layer adjacent to the luminescent region and an electrically conductive light absorbing layer.

There is also provided in embodiments an organic light emitting device comprising in sequence:

(a) a cathode including:

(i) an electrically conductive light absorbing layer, and

(ii) a substantially transparent electron injecting layer;

(b) a luminescent region including an organic electroluminescent material; and

(c) an anode that is substantially transparent to light.

There is provided in additional embodiments an organic light emitting device comprising in sequence:

(a) a cathode that is substantially transparent to light;

(b) a luminescent region including an organic electroluminescent material; and

1 (c) an anode including:

2 (i) a substantially transparent hole injecting layer, and

3 (ii) an electrically conductive light absorbing layer.

4
5 **BRIEF DESCRIPTION OF THE DRAWINGS**
6

7 Other aspects of the present invention will become apparent as the following
8 description proceeds and upon reference to the Figures which represent illustrative
9 embodiments:

10 FIG. 1 is a schematic, elevational view in cross-section of a first embodiment of
11 the present OLED;

12 FIG. 2 is a schematic, elevational view in cross-section of a second embodiment
13 of the present OLED;

14 FIG. 3 is a schematic, elevational view in cross-section of a third embodiment of
15 the present OLED; and

16 FIG. 4 is a schematic, elevational view in cross-section of a fourth embodiment
17 of the present OLED.

18 Unless otherwise noted, the same reference numeral in different Figures refers to
19 the same or similar feature.

20
21 **DETAILED DESCRIPTION**
22

23 The present organic light emitting device is composed of at least a first
24 electrode; a second electrode; and a luminescent region including an organic
25 electroluminescent material between the first electrode and the second electrode,
26 wherein one of the first electrode and the second electrode includes both a substantially
27 transparent charge injecting layer adjacent to the luminescent region and an electrically
28 conductive light absorbing layer. Either the cathode or the anode can include the
29 charge injecting layer and the electrically conductive light absorbing layer. The charge
30 injecting layer may be either an electron injecting layer (in the case of a cathode) or a
31 hole injecting layer (in the case of an anode). The present organic light emitting device
32 may include a substrate either as a separate layer adjacent to one of the electrodes or
33 incorporated into one of the electrodes (e.g., the electrically conductive light absorbing
34 layer that is part of an electrode includes in embodiments a substrate material to result
35 in an electrically conductive light absorbing substrate).

1 substrate materials can also be selected provided, for example, that the materials can
2 effectively support the other layers, and do not interfere with the device functional
3 performance.

4 An opaque substrate can comprise various suitable materials including, for
5 example, polymeric components like polyesters such as MYLAR®, polycarbonates,
6 polyacrylates, polymethacrylates, polysulfones, and the like, which contain coloring
7 agents or dyes such as carbon black. The substrate can also be comprised of
8 silicon such as amorphous silicon, polycrystalline silicon, single crystal silicon, and the
9 like. Another class of materials that can be used in the substrate are ceramics such as
10 metallic compounds like metal oxides, halides, hydroxides, sulfides and others.

11 The substrate may have a thickness ranging for example from about 10 to about
12 5,000 micrometers, and more particularly from about 25 to about 1,000 micrometers.

13 A substantially transparent anode (such as that used in the OLED devices of
14 FIGS. 1-2) can comprise suitable positive charge injecting materials such as indium tin
15 oxide (ITO), silicon, tin oxide, and metals with a work function ranging from about 4
16 eV to about 6 eV such as gold, platinum, and palladium. Other suitable materials for
17 the anode include, but are not limited to, electrically conductive carbon, π -conjugated
18 polymers such as polyaniline, polythiophene, polypyrrole, and the like having, for
19 example, a work function equal to, or greater than, about 4 eV, and particularly from
20 about 4 eV to about 6 eV. A substantially transparent anode can comprise very thin
21 substantially transparent metallic layers, comprising a metal with a work function
22 ranging from about 4 eV to about 6 eV such as gold, palladium and the like, having a
23 thickness, for example, from about 10 Å to about 200 Å, and, particularly, from about
24 30 Å to about 100 Å. Additional suitable forms of the anode are disclosed in U.S.
25 Patents 4,885,211 and 5,703,436, which are incorporated herein by reference in their
26 entirety.

27 The thickness of the substantially transparent anode can range from about 10 Å to
28 about 50,000 Å, with the preferred range depending on the optical constants of the
29 anode material. One illustrative range of anode thickness is from about 300 Å to about
30 3,000 Å. Of course, a thickness outside of this range can also be used.

31 A substantially transparent cathode (such as that used in the OLED devices of
32 FIGS. 3-4) can comprise very thin substantially transparent metallic layers comprising
33 a metal with a work function ranging from about 2 eV to about 4 eV, such as Mg, Ag,
34 Al, Ca, In, Li and their alloys such as Mg:Ag alloys, comprised of, for example, from
35 about 80 to 95 volume percent of Mg and about 20 to about 5 volume percent of Ag,

1 and Li:Al alloys, comprised of, for example, from about 90 to 99 volume percent of Al,
2 and from about 10 to about 1 volume percent of Li, and the like, having a thickness,
3 for example, from about 10 Å to about 200 Å, and, particularly, from about 30 Å to
4 about 100 Å. Other substantially transparent cathodes are disclosed in US Serial No.
5 09/800,716, cited earlier, and incorporated herein by reference in its entirety, such as
6 cathodes comprising a layer, of thickness from about 100 Å to about 10,000 Å, and
7 particularly from about 500 Å to about 5,000 Å, comprised of a metal, an organic
8 material, and a third component which can be a metal, an organic material, or any other
9 material. One embodiment is a cathode composed of a layer comprised of about 47.4
10 volume percent of Mg, about 5.2 volume percent of Ag, and about 47.4 volume percent
11 of tris(8-hydroxyquinoline) aluminum (AlQ₃). Additional suitable forms of
12 substantially transparent cathodes are disclosed in U.S. Patent 5,703,436, which is
13 incorporated herein by reference in its entirety.

14 The thickness of the substantially transparent cathode can range from about 10 Å
15 to about 50,000 Å, with the preferred range depending on the optical constants of the
16 cathode material. One illustrative range of cathode thickness is from about 30 Å to
17 about 100 Å. Another illustrative range is from about 50 Å to about 500 Å. Of course,
18 a thickness outside of this range can also be used.

19 A substantially transparent electron injecting layer can include very thin
20 substantially transparent metallic layers, composed of a metal with a work function
21 ranging from about 2 eV to about 4 eV, such as Mg, Ag, Al, Ca, In, Li and their alloys
22 such as Mg:Ag alloys composed of, for example, from about 80 to 95 volume percent
23 of Mg and about 20 to about 5 volume percent of Ag, and Li:Al alloys, composed of,
24 for example, from about 90 to 99 volume percent of Al, and from about 10 to about 1
25 volume percent of Li, and the like, having a thickness, for example, from about 10 Å to
26 about 200 Å, and, particularly, from about 30 Å to about 100 Å. Other substantially
27 transparent electron injecting layers are disclosed in US Serial No. 09/800,716, cited
28 earlier, and incorporated herein by reference in its entirety, such as a layer, of
29 thickness from about 100 Å to about 10,000 Å, and particularly from about 500 Å to
30 about 5,000 Å, comprised of a metal, an organic material, and a third component which
31 can be a metal, an organic material, or any other material. One embodiment is a layer
32 composed of about 47.4 volume percent of Mg, about 5.2 volume percent of Ag, and
33 about 47.4 volume percent of tris(8-hydroxyquinoline) aluminum (AlQ₃).

34 The thickness of a substantially transparent electron injecting layer can range
35 from about 10 Å to about 50,000 Å, with the preferred range depending on the optical

constants of the cathode material. One illustrative range of thickness of the electron injecting layer is from about 30 Å to about 100 Å. Another illustrative range is from about 50 Å to about 500 Å. Of course, a thickness outside of this range can also be used.

A substantially transparent hole injecting layer can be composed of suitable positive charge injecting materials such as indium tin oxide (ITO), silicon, tin oxide, and metals with a work function ranging from about 4 eV to about 6 eV, such as, gold, platinum, and palladium. Other suitable materials for the hole injecting layer include, but are not limited to, electrically conductive carbon, π -conjugated polymers such as polyaniline, polythiophene, polypyrrole, and the like having, for example, a work function equal to, or greater than, about 4 eV, and particularly from about 4 eV to about 6 eV. A substantially transparent hole injecting material can be composed of very thin substantially transparent metallic layers, comprising a metal with a work function ranging from about 4 eV to about 6 eV, such as gold, palladium and the like, having a thickness, for example, from about 10 Å to about 200 Å, and, particularly, from about 30 Å to about 100 Å. Additional suitable forms of hole injecting layers are disclosed in U.S. Patents 4,885,211 and 5,703,436, which are incorporated herein by reference in their entirety.

The thickness of a substantially transparent hole injecting layer can range, for example, from about 10 Å to about 50,000 Å, with the preferred range depending on the optical constants of the selected material. One illustrative range of thickness of the hole injecting layer is from about 30 Å to about 100 Å. Another illustrative range is from about 50 Å to about 500 Å. Of course, a thickness outside of this range can also be used.

Where the charge injecting layer and the light absorbing layer may undesirably react with one another if the two layers are in contact, or where the charge injecting layer may be damaged during coating of the light absorbing layer on it, thereby degrading the performance of the organic light emitting device, the presence of an intervening buffer layer will prevent or minimize such reactions or damage. A buffer layer, therefore, will include a material that may not undesirably react with both the charge injecting layer and the light absorbing layer, and also that may protect the charge injecting layer from possible damage during coating of the light absorbing layer on it. Examples of materials that can be selected to comprise the buffer layer are metallic compounds such as metal oxides like Al_2O_3 , metal halides like MgF_2 , and others. Other materials that can be selected to form the buffer layer include porphyrins like

1 metal phthalocyanine such as copper phthalocyanine. Preferred materials that can be
2 used include SiO, SiO₂ or mixtures thereof. The buffer layer is preferably non-
3 reflective. In embodiments, the buffer layer is partially or substantially transparent
4 and/or light absorbing.

5 The thickness of the buffer layer is selected depending on the materials used to
6 form this buffer layer such that significant cross directional conduction from the
7 electrically conductive light absorbing layer to the charge injecting layer across the
8 buffer layer is not interrupted by the buffer layer. Typically, the thickness of the buffer
9 layer can range from about 10 Å to about 5,000 Å, particularly from about 50 Å to
10 about 1,000 Å.

11 The electrically conductive light absorbing layer can include a single material
12 that combines the desired light absorption and electrical conduction properties such as
13 carbon (e.g., graphite and C₆₀), Si, Ge and the like, a metal such as Mo, Ni, Cr, Pd, V,
14 Se, In and their alloys such as INCONNEL™, NICHROME™, and the like, or a
15 conductive light absorbing metal oxide. The electrically conductive light absorbing
16 layer can also be comprised of a blend of two or more materials, wherein at least one of
17 the materials is a light absorbing material such as an organic dye or pigment, such as a
18 phthalocyanine, a perinone, a perylene, a perylene dimer, and the like, and wherein one
19 of the materials is a conductive material, such as a metal like Ag, Al, Au, Cu, Mg, In
20 and the like. When the light absorbing layer is comprised of two or more materials, the
21 concentration of each material in the layer can be adjusted in order to obtain the desired
22 electrical conduction and light absorption properties. For example, the layer can
23 comprise from about 50 volume percent to about 99 volume percent of a light
24 absorbing material and from about 50 volume percent to about 1 volume percent of an
25 electrically conductive material.

26 The electrically conductive light absorbing layer may have a thickness ranging
27 for example from about 10 Å to about 10,000 Å, where preferred ranges for the
28 thickness can be selected depending on the materials used in forming the layer. One
29 illustrative thickness range is from about 10 Å to about 500 Å. Another illustrative
30 thickness range is from about 500 Å to about 5,000 Å. Yet, another illustrative
31 thickness range is from about 5,000 Å to about 10,000 Å. Of course, a thickness
32 outside of these ranges can also be used.

33 The phrase "light absorbing" indicates noticeable extinction of light, for example,
34 at least about 50% extinction of light entering the light absorbing layer, particularly at
35 least about 90% extinction of light entering the light absorbing layer. The light

1 The luminescent region is composed of an organic electroluminescent material.
2 Electroluminescent materials include, for example, polyphenylenevinylenes such as
3 poly(p-phenylenevinylene) PPV, poly(2-methoxy-5-(2-ethylhexyloxy)1,4-
4 phenylenevinylene) MEHPPV and poly(2,5-dialkoxyphenylenevinylene) PDMOPV,
5 and other materials disclosed in U.S. Patent 5,247,190, which is incorporated herein by
6 reference in its entirety; polyphenylenes, such as poly(p-phenylene) PPP, ladder-poly-
7 *para*-phenylene (LPPP), and poly(tetrahydropyrene) PTHP; and polyfluorenes, such as
8 poly(9,9-di-n-octylfluorene-2,7-diyl), poly(2,8-(6,7,12,12-tetraalkylindenofluorene)
9 and copolymers containing fluorenes such as fluorene-amine copolymers (see e.g.,
10 Bernius et al., "Developmental Progress of Electroluminescent Polymeric Materials
11 and Devices," Proceedings of SPIE Conference on Organic Light Emitting Materials
12 and Devices III, Denver, Colorado, July 1999, Volume 3797, p. 129).

13 Another class of organic electroluminescent materials that can be utilized in the
14 luminescent region includes, but is not limited to, the metal oxinoid compounds as
15 disclosed in U.S. Patents 4,539,507; 5,151,629; 5,150,006; 5,141,671 and 5,846,666,
16 each incorporated herein by reference in its entirety. Illustrative examples include
17 tris(8-hydroxyquinolate) aluminum (AlQ3), which is one preferred example, and
18 bis(8-hydroxyquinolato)-(4-phenylphenolato) aluminum (BALq) which is another
19 preferred example. Other examples of this class of materials include tris(8-
20 hydroxyquinolate) gallium, bis(8-hydroxyquinolate) magnesium, bis(8-
21 hydroxyquinolate) zinc, tris(5-methyl-8-hydroxyquinolate) aluminum, tris(7-
22 propyl-8-quinolinolato) aluminum, bis[benzo{f}-8-quinolate]zinc, bis(10-
23 hydroxybenzo[h]quinolate) beryllium, and the like, and metal thioxinoid compounds
24 disclosed in U.S. Patent 5,846,666 (which is incorporated herein by reference in its
25 entirety), such as metal thioxinoid compounds of bis(8-quinolinethiolato)zinc, bis(8-
26 quinolinethiolato)cadmium, tris(8-quinolinethiolato)gallium, tris(8-
27 quinolinethiolato)indium, bis(5-methylquinolinethiolato)zinc, tris(5-
28 methylquinolinethiolato)gallium, tris(5-methylquinolinethiolato)indium, bis(5-
29 methylquinolinethiolato)cadmium, bis(3-methylquinolinethiolato)cadmium, bis(5-
30 methylquinolinethiolato)zinc, bis[benzo{f}-8-quinolinethiolato]zinc, bis[3-
31 methylbenzo{f}-8-quinolinethiolato]zinc, bis[3,7-dimethylbenzo{f}-8-
32 quinolinethiolato]zinc, and the like. Preferred materials are bis(8-
33 quinolinethiolato)zinc, bis(8-quinolinethiolato)cadmium, tris(8-
34 quinolinethiolato)gallium, tris(8-quinolinethiolato)indium and bis[benzo{f}-8-
35 quinolinethiolato]zinc.

1 More specifically, a class of organic electroluminescent materials that can be
2 used in the luminescent region comprises stilbene derivatives, such as those disclosed
3 in U.S. Patent 5,516,577, incorporated herein by reference in its entirety. A preferred
4 stilbene derivative is 4,4'-bis(2,2-diphenylvinyl)biphenyl.

5 Another class of suitable organic electroluminescent materials suitable for
6 utilizing in the luminescent region is the oxadiazole metal chelates. These materials
7 include bis[2-(2-hydroxyphenyl)-5-phenyl-1,3,4-oxadiazolato]zinc; bis[2-(2-
8 hydroxyphenyl)-5-phenyl-1,3,4-oxadiazolato]beryllium; bis[2-(2-hydroxyphenyl)-5-(1-
9 naphthyl)-1,3,4-oxadiazolato]zinc; bis[2-(2-hydroxyphenyl)-5-(1-naphthyl)-1,3,4-
10 oxadiazolato]beryllium; bis[5-biphenyl-2-(2-hydroxyphenyl)-1,3,4-oxadiazolato]zinc;
11 bis[5-biphenyl-2-(2-hydroxyphenyl)-1,3,4-oxadiazolato]beryllium; bis(2-
12 hydroxyphenyl)-5-phenyl-1,3,4-oxadiazolato]lithium; bis[2-(2-hydroxyphenyl)-5-p-
13 tolyl-1,3,4-oxadiazolato]zinc; bis[2-(2-hydroxyphenyl)-5-p-tolyl-1,3,4-
14 oxadiazolato]beryllium; bis[5-(p-tert-butylphenyl)-2-(2-hydroxyphenyl)-1,3,4-
15 oxadiazolato]zinc; bis[5-(p-tert-butylphenyl)-2-(2-hydroxyphenyl)-1,3,4-
16 oxadiazolato]beryllium; bis[2-(2-hydroxyphenyl)-5-(3-fluorophenyl)-1,3,4-
17 oxadiazolato]zinc; bis[2-(2-hydroxyphenyl)-5-(4-fluorophenyl)-1,3,4-
18 oxadiazolato]zinc; bis[2-(2-hydroxyphenyl)-5-(4-fluorophenyl)-1,3,4-
19 oxadiazolato]beryllium; bis[5-(4-chlorophenyl)-2-(2-hydroxyphenyl)-1,3,4-
20 oxadiazolato]zinc; bis[2-(2-hydroxyphenyl)-5-(4-methoxyphenyl)-1,3,4-
21 oxadiazolato]zinc; bis[2-(2-hydroxy-4-methylphenyl)-5-phenyl-1,3,4-
22 oxadiazolato]zinc; bis[2- α -(2-hydroxynaphthyl)-5-phenyl-1,3,4-oxadiazolato]zinc;
23 bis[2-(2-hydroxyphenyl)-5-p-pyridyl-1,3,4-oxadiazolato]zinc; bis[2-(2-
24 hydroxyphenyl)-5-p-pyridyl-1,3,4-oxadiazolato]beryllium; bis[2-(2-hydroxyphenyl)-5-
25 (2-thiophenyl)-1,3,4-oxadiazolato]zinc; bis[2-(2-hydroxyphenyl)-5-phenyl-1,3,4-
26 thiadiazolato]zinc; bis[2-(2-hydroxyphenyl)-5-phenyl-1,3,4-thiadiazolato]beryllium;
27 bis[2-(2-hydroxyphenyl)-5-(1-naphthyl)-1,3,4-thiadiazolato]zinc; and bis[2-(2-
28 hydroxyphenyl)-5-(1-naphthyl)-1,3,4-thiadiazolato]beryllium, and the like; and the
29 triazines including those disclosed in U.S. Patent 6,057,048, which is incorporated
30 herein by reference in its entirety.

31 The luminescent region can further include from about 0.01 weight percent to
32 about 25 weight percent of a luminescent material as a dopant. Examples of dopant
33 materials that can be utilized in the luminescent region are fluorescent materials, such
34 as coumarin, dicyanomethylene pyranes, polymethine, oxabenzanthrane, xanthene,
35 pyrylium, carbostyl, perylene, and the like. Another preferred class of fluorescent

materials are quinacridone dyes. Illustrative examples of quinacridone dyes include quinacridone, 2-methylquinacridone, 2,9-dimethylquinacridone, 2-chloroquinacridone, 2-fluoroquinacridone, 1,2-benzoquinacridone, N,N'-dimethylquinacridone, N,N'-dimethyl-2-methylquinacridone, N,N'-dimethyl-2,9-dimethylquinacridone, N,N'-dimethyl-2-chloroquinacridone, N,N'-dimethyl-2-fluoroquinacridone, N,N'-dimethyl-1,2-benzoquinacridone, and the like as disclosed in U.S. Patents 5,227,252; 5,276,381 and 5,593,788, each incorporated herein by reference in its entirety. Another class of fluorescent materials that may be used is fused ring fluorescent dyes. Exemplary suitable fused ring fluorescent dyes include perylene, rubrene, anthracene, coronene, phenanthrene, pyrene and the like, as disclosed in U.S. Patent 3,172,862, which is incorporated herein by reference in its entirety. Also, fluorescent materials include butadienes, such as 1,4-diphenylbutadiene and tetraphenylbutadiene, and stilbenes, and the like, as disclosed in U.S. Patents 4,356,429 and 5,516,577, each incorporated herein by reference in its entirety. Other examples of fluorescent materials that can be used are those disclosed in U.S. Patent 5,601,903, which is incorporated herein by reference in its entirety.

Additionally, luminescent dopants that can be utilized in the luminescent region are the fluorescent dyes disclosed in U.S. Patent 5,935,720 (which is incorporated herein by reference in its entirety) such as 4-(dicyanomethylene)-2-*I-propyl*-6-(1,1,7,7-tetramethyljulolidyl-9-enyl)-4*H*-pyran (DCJTB); the lanthanide metal chelate complexes, such as for example, tris(acetylacetonato)(phenanthroline) terbium, tris(acetylacetonato)(phenanthroline) europium, and tris(thenoyltrifluoroacetato)(phenanthroline) europium, and those disclosed in Kido et al., "White light emitting organic electroluminescent device using lanthanide complexes," Jpn. J. Appl. Phys., Volume 35, pp. L394-L396 (1996), which is incorporated herein by reference in its entirety; and phosphorescent materials, such as organometallic compounds containing heavy metal atoms that lead to strong spin-orbit coupling, such as those disclosed in Baldo et.al., "Highly efficient organic phosphorescent emission from organic electroluminescent devices," Letters to Nature, Volume 395, pp. 151-154 (1998), which is incorporated herein by reference in its entirety. Preferred examples include 2,3,7,8,12,13,17,18-octaethyl-21*H*23*H*-phorpine platinum(II) (PtOEP) and *fac* tris(2-phenylpyridine)iridium (Ir(ppy)₃).

The luminescent region can also include one or more materials with hole-transporting properties. Examples of hole-transporting materials that can be utilized in the luminescent region include polypyrrole, polyaniline, poly(phenylene vinylene),

polythiophene, polyarylamine as disclosed in U.S. Patent 5,728,801, which is incorporated herein by reference in its entirety, and their derivatives, and known semiconductive organic materials; porphyrin derivatives such as 1,10,15,20-tetraphenyl-21H,23H-porphyrin copper (II) disclosed in U.S. Patent 4,356,429, incorporated herein by reference in its entirety; copper phthalocyanine, copper tetramethyl phthalocyanine; zinc phthalocyanine; titanium oxide phthalocyanine; magnesium phthalocyanine; and the like

A specific class of hole transporting materials that can be utilized in the luminescent region are the aromatic tertiary amines such as those disclosed in U.S. Patent 4,539,507, which is incorporated herein by reference in its entirety. Suitable exemplary aromatic tertiary amines include, but are not limited to, bis(4-dimethylamino-2-methylphenyl)phenylmethane, N,N,N-tri(p-tolyl)amine, 1,1-bis(4-di-p-tolylaminophenyl)cyclohexane, 1,1-bis(4-di-p-tolylaminophenyl)-4-phenyl cyclohexane, N,N'-diphenyl-N,N'-bis(3-methylphenyl)-1,1'-biphenyl-4,4'-diamine, N,N'-diphenyl-N,N'-bis(3-methylphenyl)-1,1'-biphenyl-4,4'-diamine, N,N'-diphenyl-N,N'-bis(4-methoxyphenyl)-1,1'-biphenyl-4,4'-diamine, N,N,N',N'-tetra-p-tolyl-1,1'-biphenyl-4,4'-diamine, N,N'-di-1-naphthyl-N,N'-diphenyl-1,1'-biphenyl-4,4'-diamine, mixtures thereof and the like. Another class of aromatic tertiary amines are polynuclear aromatic amines. Examples of these polynuclear aromatic amines include, but are not limited to, N,N-bis-[4'-(N-phenyl-N-m-tolylamino)-4-biphenyl]aniline; N,N-bis-[4'-(N-phenyl-N-m-tolylamino)-4-biphenyl]-m-toluidine; N,N-bis-[4'-(N-phenyl-N-m-tolylamino)-4-biphenyl]-p-toluidine; N,N-bis-[4'-(N-phenyl-N-p-tolylamino)-4-biphenyl]aniline; N,N-bis-[4'-(N-phenyl-N-p-tolylamino)-4-biphenyl]-m-toluidine; N,N-bis-[4'-(N-phenyl-N-p-tolylamino)-4-biphenyl]-p-toluidine; N,N-bis-[4'-(N-phenyl-N-p-chlorophenylamino)-4-biphenyl]-m-toluidine; N,N-bis-[4'-(N-phenyl-N-m-chlorophenylamino)-4-biphenyl]-m-toluidine; N,N-bis-[4'-(N-phenyl-N-m-chlorophenylamino)-4-biphenyl]-p-toluidine; N,N-bis-[4'-(N-phenyl-N-m-tolylamino)-4-biphenyl]-p-chloroaniline; N,N-bis-[4'-(N-phenyl-N-p-tolylamino)-4-biphenyl]-m-chloroaniline; N,N-bis-[4'-(N-phenyl-N-m-tolylamino)-4-biphenyl]-1-aminonaphthalene, mixtures thereof and the like; 4,4'-bis(9-carbazolyl)-1,1'-biphenyl compounds, such as 4,4'-bis(9-carbazolyl)-1,1'-biphenyl and 4,4'-bis(3-methyl-9-carbazolyl)-1,1'-biphenyl, and the like.

A specific class of the hole transporting materials that can be used in the luminescent region are the indolo-carbazoles, such as those disclosed in U.S. Patents 5,942,340 and 5,952,115, each incorporated herein by reference in its entirety, such as

1 5,11-di-naphthyl-5,11-dihydroindolo[3,2-b]carbazole, and 2,8-dimethyl-5,11-di-
2 naphthyl-5,11-dihydroindolo[3,2-b]carbazole; N,N,N',N'-tetraarylbenzidines, wherein
3 aryl may be selected from phenyl, m-tolyl, p-tolyl, m-methoxyphenyl, p-
4 methoxyphenyl, 1-naphthyl, 2-naphthyl and the like. Illustrative examples of
5 N,N,N',N'-tetraarylbenzidine are N,N'-di-1-naphthyl -N,N'- diphenyl-1,1'-biphenyl-4,4'-
6 diamine, which is more preferred; N,N'-bis(3-methylphenyl) -N,N'- diphenyl-1,1'-
7 biphenyl-4,4'-diamine; N,N'-bis(3-methoxyphenyl) -N,N'- diphenyl-1,1'-biphenyl-4,4'-
8 diamine, and the like. Preferred hole transporting materials that can be used in the
9 luminescent region are the naphthyl-substituted benzidine derivatives.

10 The luminescent region can also include one or more materials with electron
11 transporting properties. An example of electron transporting materials that can be
12 utilized in the luminescent region is polyfluorenes, such as poly(9,9-di-n-octylfluorene-
13 2,7-diyl), poly(2,8-(6,7,12,12-tetraalkylindenofluorene) and copolymers containing
14 fluorenes such as fluorene-amine copolymers, as disclosed in incorporated Bernius et
15 al., Proceedings of SPIE Conference on Organic Light Emitting Materials and Devices
16 III, Denver, Colorado, July 1999, Volume 3797, p. 129.

17 Other examples of electron transporting materials that can be utilized in the
18 luminescent region can be selected from the metal oxinoid compounds, the oxadiazole
19 metal chelate compounds, the triazine compounds and the stilbene compounds,
20 examples of which have been described above in detail.

21 In embodiments where the luminescent region includes one or more hole
22 transport material and/or one or more electron transport material in addition to the
23 organic electroluminescent material(s), the organic electroluminescent material, the
24 hole transport material(s), and/or the electron transport material(s) can be formed in
25 separate regions, such as the OLEDs disclosed in U.S. Patents 4,539,507; 4,720,432
26 and 4,769,292; or in the same region thus forming mixed regions of two or more
27 materials, such as the OLEDs disclosed in U.S. Patent 6,130,001, and in U.S.
28 Application Serial Nos. 09/357,551, filed on July 20, 1999; 09/606,670, filed on June
29 30, 2000; and 09/770,159, filed on January 26, 2001. The disclosures of these patents
30 and patent applications are incorporated herein by reference in their entirety.

31 The thickness of the luminescent region can vary for example, from about 10 Å
32 to about 10,000 Å, typically from about 200 Å to about 2,000 Å, and particularly from
33 about 500 Å to about 1,500 Å. In embodiments wherein the luminescent region
34 includes two or more layers, the thickness of each layer can, for example, be from

1 about 10 Å to about 5,000 Å, typically from about 50 Å to about 2,000 Å, and
2 particularly from about 100 Å to about 1,500 Å.

3 The organic light emitting device can be fabricated by sequentially forming the
4 layers comprising the organic light emitting device on the substrate, using any suitable
5 thin film forming technique, typically, spin coating or deposition by thermal
6 evaporation in vacuum. In embodiments, the charge injecting layer, the light
7 absorbing layer, and the optional buffer layer and metallic layer are deposited by
8 thermal evaporation in vacuum.

9 More details about fabrication and operation of organic light emitting devices are
10 disclosed, for example, in U.S. Patents 4,539,507 and 4,769,292, and in copending
11 U.S. Applications No. 09/357,551, filed on July 20, 1999; No. 09/606,670, filed on
12 June 30, 2000; and No. 09/770,159, filed on January 26, 2001, the disclosure of each
13 patent and patent application being totally incorporated herein by reference.

14 The invention will now be described in detail with respect to specific preferred
15 embodiments thereof, it being understood that these examples are intended to be
16 illustrative only and the invention is not intended to be limited to the materials,
17 conditions, or process parameters recited herein. All percentages and parts are by
18 weight unless otherwise indicated.

20 EXAMPLE

21
22 An inventive organic light emitting device according to the device structure of
23 FIG. 1 was fabricated. The organic light emitting device was composed of in the
24 sequence:

25 a substrate made of glass of about 1 mm thickness;

26 an anode composed of indium tin oxide of about 200 nm thickness;

27 a luminescent region composed of a hole transport layer of thickness about 60 nm
28 coated on the anode, made of *N,N'*-di(naphthalene-1-yl)-*N,N'*-diphenyl-benzidine
29 (NPB), and a luminescent electron transport layer, about 75 nm thick, coated on the
30 hole transport layer made of tris (8-hydroxyquinoline) aluminum (AlQ3); and

31 a cathode including: (a) a substantially transparent electron injecting layer, about
32 4 nm thick, made of Mg:Ag alloy (9:1 by volume), (b) a buffer layer, about 200 nm
33 thick, made of SiO, (c) a light absorbing layer, about 500 nm thick, made of a black
34 pigment material, Bis (1,8-Naphthimidazo) perinone, and (d) a metallic layer, about
35 200 nm thick, made of Ag.

COMPARATIVE EXAMPLE

A comparative organic light emitting device, similar to the inventive OLED of the Example but which included a conventional cathode, was fabricated and evaluated. The organic light emitting device was composed of in the sequence:

a substrate made of glass of thickness about 1 mm;

an anode composed of indium tin oxide, of thickness about 200 nm;

a luminescent region, composed of a hole transport layer of thickness about 60 nm coated on the anode, made of *N,N'*-di(naphthalene-1-yl)-*N,N'*-diphenyl-benzidine (NPB), and a luminescent electron transport layer, about 75 nm thick, coated on the hole transport layer made of tris (8-hydroxyquinoline) aluminum (AlQ3); and

a cathode including: (a) an electron injecting layer, about 120 nm thick, made of Mg:Ag alloy (9:1 by volume); and (b) a metallic layer, about 80 nm thick, made of Ag.

Both the inventive and comparative organic light emitting devices including the cathode layers were fabricated by thermal evaporation in vacuum (about 5×10^{-6} torr.) in the same pump down cycle.

Visual examination of the inventive and comparative organic light emitting devices revealed negligible reflectivity of the cathode of the inventive organic light emitting device, whereas the cathode of the comparative organic light emitting device was highly reflective of ambient illumination, giving it a mirror-like appearance.

When operated under 7 volts, emission from the inventive organic light emitting device demonstrated excellent visibility, regardless of the viewing angle, even when viewed under strong ambient illumination from a 200W flood light source placed about 15 cms apart from the device. On the other hand, emission from the comparative organic light emitting device, when operated under 7 volts, was almost invisible under the same ambient illumination conditions.

Other modifications of the present invention may occur to those skilled in the art based upon a reading of the present disclosure and these modifications are intended to be included within the scope of the present invention.